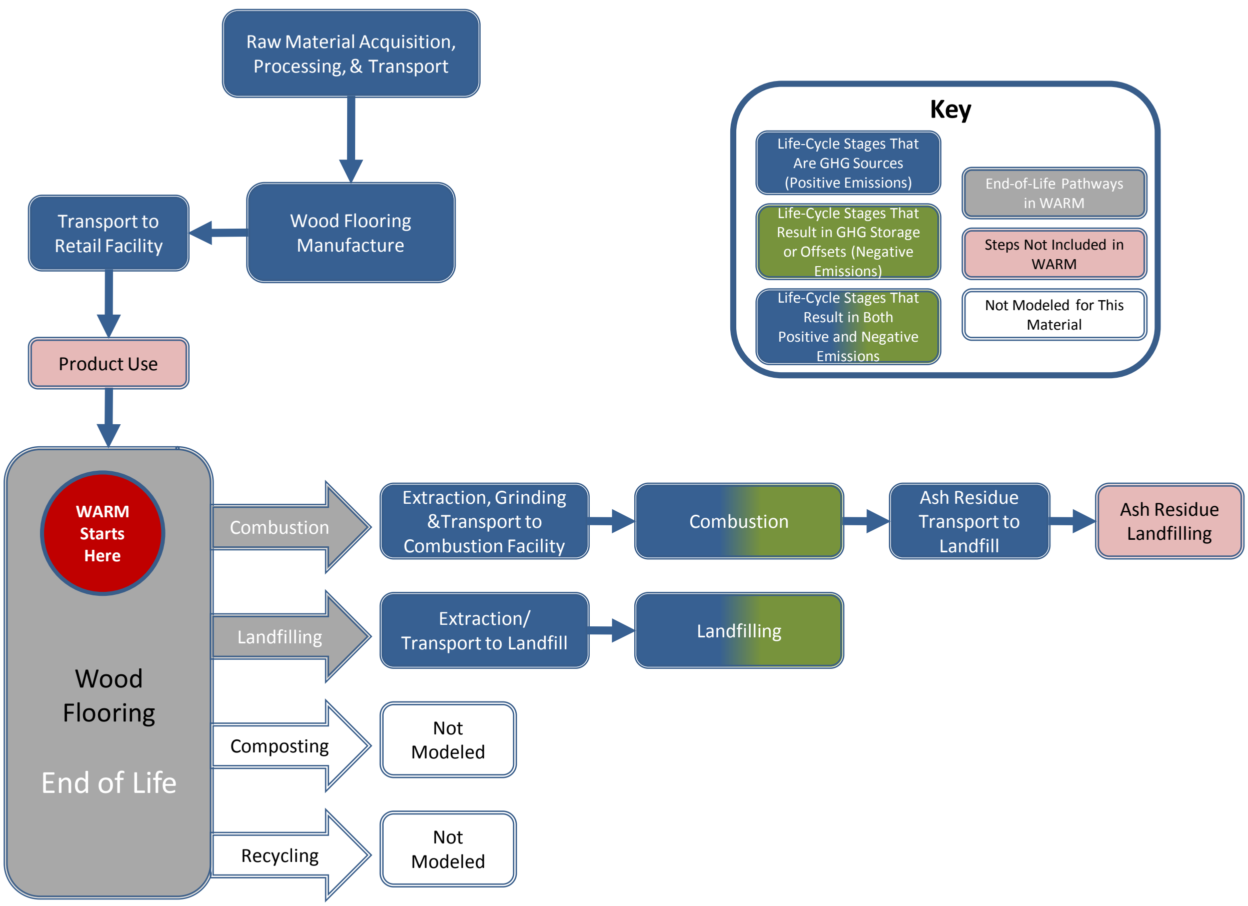
WOOD FLOORING

1. INTRODUCTION TO WARM AND WOOD FLOORING

This chapter describes the methodology used in EPA's Waste Reduction Model (WARM) to estimate streamlined life-cycle greenhouse gas (GHG) emission factors for wood flooring beginning at the waste generation reference point.[1] The WARM GHG emission factors are used to compare the net emissions associated with wood flooring in the following three waste management alternatives: source reduction, combustion, and landfilling. Exhibit 1 shows the general outline of materials management pathways for wood flooring in WARM. For background information on the general purpose and function of WARM emission factors, see the Introduction & Overview chapter. For more information on Source Reduction, Combustion, and Landfilling, see the chapters devoted to those processes. WARM also allows users to calculate results in terms of energy, rather than GHGs. The energy results are calculated using the same methodology described here but with slight adjustments, as explained in the Energy Impacts chapter.

Exhibit 1: Life Cycle of Wood Flooring in WARM



Solid hardwood flooring is an established floor covering in the United States. Hubbard and Bowe (2008, p. 3) estimate that there are between 150 to 200 facilities that manufacture hardwood flooring in the country, accounting for 483 million square feet of annual production.

[1] EPA would like to thank Richard Bergman and Ken Skog of the USDA Forest Service, and Scott Bowe of the University of Wisconsin, for their efforts at improving these estimates.

2. LIFECYCLE ASSESSMENT AND EMISSION FACTOR RESULTS

The streamlined[2] life-cycle boundaries in WARM start at the point of waste generation, or the moment a material is discarded, as the reference point and only considers upstream GHG emissions when the production of new materials is affected by material management decisions. Recycling and Source Reduction are the two materials management options that impact the upstream production of materials, and consequently are the only management options that include upstream GHG emissions. For more information on evaluating upstream emissions, see the chapters on Recycling and Source Reduction.

WARM considers emission factors for source reduction, combustion, and landfilling for wood flooring. As Exhibit 2 illustrates, the GHG sources and sinks relevant to wood flooring in this analysis are spread across all three sections of the life-cycle assessment: raw materials acquisition and manufacturing (RMAM), changes in forest or soil carbon storage, and materials management.

Exhibit 2: Wood Flooring GHG Sources and Sinks from Relevant Materials Management Pathways

Materials Management Strategies for Wood Flooring	GHG Sources and Sinks Relevant to Wood Flooring		
	Raw Materials Acquisition and Manufacturing	**Changes in Forest or Soil Carbon Storage**	**End of Life**
Source Reduction	**Offsets** • Avoided wood harvesting • Avoided lumber production • Avoided hardwood flooring production • Avoided transport to sawmill • Avoided on-site transport at sawmill • Avoided transport to flooring mill	**Offsets** • Increase in forest carbon storage **Emissions** • Decrease in carbon storage in in-use wood products	NA
Recycling	Not modeled in WARM		
Composting	Not modeled in WARM		
Combustion	NA	NA	**Emissions** • Transport to waste-to-energy facility • Transport of ash residue to landfill • Sizing wood flooring into wood chips • Nitrous oxide emissions **Offsets** • Avoided national average mix of fossil fuel power utility emissions
Landfilling	NA	**Offsets** • Landfill carbon storage	**Emissions** • Transport to C&D landfill • Landfilling machinery • Landfill methane emissions **Offsets** • Landfilling machinery

WARM analyzes all of the GHG sources and sinks outlined in Exhibit 2 and calculates net GHG emissions per short ton of wood flooring inputs. For more detailed methodology on emission factors, please see the sections

[2] The analysis is streamlined in the sense that it examines GHG emissions only and is not a comprehensive environmental analysis of all environmental impacts from municipal solid waste management options.

below on individual waste management strategies. Exhibit 3 below outlines the net GHG emissions for wood flooring under each materials management option.

Exhibit 3: Net Emissions for Wood Flooring under Each Materials Management Option ($MTCO_2E$/Short Ton)

Material/Product	Net Source Reduction (Reuse) Emissions for Current Mix of Inputs	Net Recycling Emissions	Net Composting Emissions	Net Combustion Emissions	Net Landfilling Emissions
Wood Flooring	-4.06	NA	-0.18	-0.76	0.07

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
NA = Not Applicable.
NE = Not Estimated due to insufficient data.

3. RAW MATERIALS ACQUISITION AND MANUFACTURING

GHG emissions associated with raw materials acquisition and manufacturing (RMAM) are (1) GHG emissions from energy used during the acquisition and manufacturing processes, (2) GHG emissions from energy used to transport raw materials, and (3) non-energy GHG emissions resulting from manufacturing processes.[3] For virgin hardwood flooring, process energy GHG emissions result from wood harvesting, lumber production, planing, ripping, trimming, and molding. Transportation emissions are generated from transportation associated with wood harvesting, on-site transportation during lumber production and flooring manufacture, and transportation to the retail facility. EPA assumes that non-energy process GHG emissions from making wood flooring are negligible for two reasons. First, we were unable to locate data on the emissions associated with any sealants or other chemicals applied to wood flooring. Second, of the other processes that were modeled, the available data did not indicate that process non-energy emissions resulted.

To manufacture wood flooring, wood is harvested from forests and hardwood logs are transported to a sawmill. At the sawmill, hardwood logs are converted to green lumber. Next, green lumber is transported to the wood flooring mill, where it is loaded into a conventional kiln and dried to produce rough kiln-dried lumber. To bring the rough kiln-dried lumber into uniform thickness and to the desired lengths and widths, the lumber is subjected to planing, ripping, trimming, and molding. The output of these processes is unfinished solid strip or plank flooring with tongue-and-groove joinings. Finally, coatings and sealants can be applied to wood flooring in "pre-finishing" that occurs at the manufacturing facility, or on-site. Coatings and sealants applied to reclaimed wood flooring are most likely applied on-site. The final wood flooring product is then packaged and transported to the retail facility.

The RMAM calculation in WARM also incorporates "retail transportation", which includes the average truck, rail, water, and other-modes transportation emissions required to transport wood flooring from the manufacturing facility to the retail/distribution point, which may be the customer or a variety of other establishments (e.g., warehouse, distribution center, wholesale outlet). The energy and GHG emissions from retail transportation are presented in Exhibit 4. Transportation emissions from the retail point to the consumer are not included. The miles travelled fuel-specific information is obtained from the *2007 U.S. Census Commodity Flow Survey* (BTS, 2007) and *Greenhouse Gas Emissions from the Management of Selected Materials* (EPA, 1998).

Exhibit 4: Retail Transportation Energy Use and GHG Emissions

Material/Product	Average Miles per Shipment	Retail Transportation Energy (Million Btu per Short Ton of Product)	Retail Transportation Emissions ($MTCO_2E$ per Short Ton of Product)
Wood Flooring	250	0.27	0.02

4. MATERIALS MANAGEMENT METHODOLOGIES

The avoided GHG emissions from source reduction of wood flooring are sizable, due to both avoided process GHG emissions and increased forest carbon storage. GHG emissions are also reduced by combusting wood

[3] Process non-energy GHG Emissions are emissions that occur during the manufacture of certain materials and are not associated with energy consumption.

flooring at end of life. Emissions increase from landfilling wood flooring; this is primarily a result of methane emissions from the decomposition of wood in the landfill, although a large portion of the carbon stored within the wood does not degrade and remains sequestered in the landfill.

4.1 SOURCE REDUCTION

When a material is source reduced, GHG emissions associated with making the material and managing the postconsumer waste are avoided. As discussed previously, under the measurement convention used in this analysis, the benefits of source reducing wood flooring come primarily from forest carbon sequestration, but additional savings also come from avoided emissions from the lumber harvesting process, production processes, and transportation. Since wood flooring is rarely manufactured from recycled inputs, the avoided emissions from source reducing wood flooring using the "current mix of inputs" is assumed to be the same as from using 100 percent virgin inputs. The avoided emissions are summarized in Exhibit 5. For more information about source reduction please refer to the chapter on Source Reduction.

Exhibit 5: Source Reduction Emission Factors for Wood Flooring ($MTCO_2E$/Short Ton)

Material	Raw Material Acquisition and Manufacturing for Current Mix of Inputs	Raw Material Acquisition and Manufacturing for 100% Virgin Inputs	Forest Carbon Storage for Current Mix of Inputs	Forest Carbon Storage for 100% Virgin Inputs	Net Emissions for Current Mix of Inputs	Net Emissions for 100% Virgin Inputs
Wood Flooring	-0.40	-0.40	-3.66	-3.66	-4.06	-4.06

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
– = Zero emissions.

4.1.1 Developing the Emission Factor for Source Reduction of Wood Flooring

To calculate the avoided GHG emissions associated with source reduction of wood flooring, EPA first looks at three components of GHG emissions from RMAM activities: process energy, transportation energy, and non-energy GHG emissions. There are no non-energy process GHG emissions from wood flooring RMAM activities. Exhibit 6 shows the results for each component and the total GHG emission factors for source reduction. More information on each component making up the final emission factor is provided below.

Exhibit 6: Raw Material Acquisition and Manufacturing Emission Factor for Virgin Production of Wood Flooring ($MTCO_2E$/Short Ton)

(a) Material/Product	(b) Process Energy	(c) Transportation Energy	(d) Process Non-Energy	(e) Net Emissions (e = b + c + d)
Wood Flooring	0.30	0.10	–	0.40

– = Zero emissions.

There are three major stages in the production of virgin hardwood flooring: wood harvesting, lumber production, and hardwood flooring production. EPA was not able to locate a comprehensive resource that addresses all three stages, so three separate sources of life-cycle data were used: Venta and Nesbit (2000), Bergman and Bowe (2008), and Hubbard and Bowe (2008).

EPA obtained data on wood harvesting from Venta and Nesbit (2000), which represents North American harvesting practices.

EPA uses estimates for wood flooring production in Bergman and Bowe (2008), which provides estimates for the process and transportation energy consumed during the manufacturing of rough kiln-dried lumber at hardwood sawmills in the U.S. Northeast/North Central regions. Process data obtained from this report includes electricity consumption (produced on- and off-site) and renewable fuel (biomass) burned in the production process. EPA assumes that the energy inputs consumed on-site are inclusive of the energy required to produce the wood residue and on-site electricity that are consumed in the lumber manufacturing process.

Finally, Hubbard and Bowe (2008) provide process data for hardwood flooring production in the U.S. Northeast/North Central regions. Process data obtained from this report includes grid electricity consumption, thermal usage (wood residue), and fossil fuels burned during flooring production. Since Hubbard and Bowe allocate energy inputs to wood flooring on a mass basis, EPA includes energy inputs to the mass of wood residue that was used to provide thermal energy for the floor manufacturing process. Hubbard and Bowe do not include the pre-finishing application of coatings in their study due to “problematic weighting and data quality” (Hubbard and Bowe, 2008). Preliminary results from a study conducted by Richard Bergman on the environmental impact of pre-finishing engineered wood flooring on-site, however, suggest that the pre-finishing process consumes significant amounts of electricity. Systems used to dry the stains and coatings applied to the wood surface and systems to control emissions from pre-finishing both consume electricity (Bergman, 2010).

The estimates in Venta and Nesbit (2000), Bergman and Bowe (2008), and Hubbard and Bowe (2008) do not include the precombustion energy of the fuels. EPA added precombustion values based on precombustion estimates by fuel types in Franklin Associates (FAL, 2007). The process energy used to produce wood flooring and the resulting emissions are shown in Exhibit 7.

Exhibit 7: Process Energy GHG Emissions Calculations for Virgin Production of Wood Flooring

Material/Product	Process Energy per Short Ton Made from Virgin Inputs (Million Btu)	Process Energy GHG Emissions ($MTCO_2E$/Short Ton)
Wood Flooring	13.10	0.30

Each of the three sources noted above contain transportation data for the various transportation steps required to produce wood flooring. Venta and Nesbit (2000) include data on transportation from the point of harvest to the sawmill. This source assumes a transportation distance of 350 kilometers by diesel-fueled truck. Bergman and Bowe (2008) include on-site transportation at the sawmill, which assumes consumption of off-road diesel, propane, and gasoline. Hubbard and Bowe (2008) include data on transportation from the sawmill to the flooring mills as well as on-site transportation at the flooring mill. This source assumes diesel-fueled trucks provide transportation to the flooring mill; on-site flooring mill transportation assumes consumption of off-road diesel, propane, and gasoline. The transportation energy used to produce wood flooring and the resulting emissions are shown in Exhibit 8.

Exhibit 8: Transportation Energy Emissions Calculations for Virgin Production of Wood Flooring

Material/Product	Transportation Energy per Short Ton Made from Virgin Inputs (Million Btu)	Transportation Energy GHG Emissions ($MTCO_2E$/Short Ton)
Wood Flooring	1.08	0.08

Note: The transportation energy and emissions in this exhibit do not include retail transportation, which is presented separately in Exhibit 4.

4.1.2 Forest Carbon Storage

In addition to RMAM emissions, forest carbon sequestration is factored into wood flooring’s total GHG emission factor for source reduction. EPA calculates the increased forest carbon sequestration from wood flooring source reduction using the approach described in the Forest Carbon Storage chapter. This approach uses the U.S. Department of Agriculture Forest Service’s (USDA-FS) FORCARB II model to estimate the change in forest carbon stocks as a function of marginal changes in harvest rates, and relates these changes to the reduction in harvesting from marginal increases in source reduction. The approach for wood flooring includes some unique characteristics not covered in the Forest Carbon Storage chapter, which are outlined here.

For wood flooring, EPA developed a separate analysis of the rates of change in carbon storage per cubic foot of wood harvested for hardwood forests. First, based on wood flooring mass balances in Hubbard and Bowe (2008) and Bergman and Bowe (2008), EPA assumes that source reducing one short ton of hardwood flooring would avoid harvesting 1.5 short tons of virgin hardwood.

Second, EPA investigated the effect that source reducing hardwood flooring has on non-soil carbon storage in forests. In contrast to FORCARB II’s baseline scenario of hardwood harvests between 2010 and 2050, the USDA Forest Service runs a scenario where harvests from hardwood forests are reduced by 1.3 percent, or 13.8

million short tons, between 2010 and 2020 to examine the change in non-soil forest carbon stocks between 2020 and 2050. Harvests in all other periods are the same as the baseline.

EPA calculates the carbon storage benefit from reducing hardwood harvests by taking the difference in non-soil forest carbon stocks between the baseline and the reduced harvest scenario. EPA divides the change in carbon stocks by the incremental change in hardwood harvests to yield the incremental forest carbon storage benefit in metric tons of carbon per short ton of avoided hardwood harvest.

Third, EPA investigates the effect that source reduction of hardwood flooring has on carbon storage and GHG emissions from use and end-of-life disposal of hardwood flooring. Based on a model of harvested wood products developed by Ken Skog at the USDA Forest Service and parameters from Skog (2008) for the half-life of in-use wood products and end-of-life disposal fates, EPA investigates the change in carbon storage and GHG emissions across five hardwood flooring product pools: use, combustion, permanent storage in landfills, temporary storage in landfills, and emission as landfill gas from landfills.

This analysis shows that for source-reduced flooring that would have otherwise been sent to landfills for disposal, the foregone permanent carbon storage in landfills is largely cancelled out by the reduction in GHG emissions from the avoided degradation of hardwood into methane in landfills. As a result, the net forest carbon storage implications are driven primarily by forest carbon storage and storage in hardwood products. Furthermore, since WARM compares source reduction of wood flooring against a baseline waste management scenario, GHG emission implications from landfilling, combustion, or other practices used to manage end-of-life flooring are accounted for in the baseline. Consequently, the net forest carbon storage benefit from source reduction only needs to consider the effect that source reduction has on increasing forest carbon storage and decreasing carbon storage in in-use wood products.

The results of the analysis are shown below in Exhibit 9 and Exhibit 10. The increase in non-soil forest carbon storage from source reducing flooring begins at 5.03 $MTCO_2E$ per short ton of hardwood flooring in 2030, and declines through 2050, although the rate of decline moderates over this time period. Carbon storage in products decreases as a result of source reducing hardwood, and this effect also declines over time as a greater fraction of hardwood leaves the in-use product pool for end-of-life management.

Over this time series, the net forest carbon storage benefit remains relatively insensitive to these changes, although moderating slightly in later years.

Exhibit 9: Components of the Cumulative Net Change in Forest Carbon Storage from Source Reduction of Wood Flooring

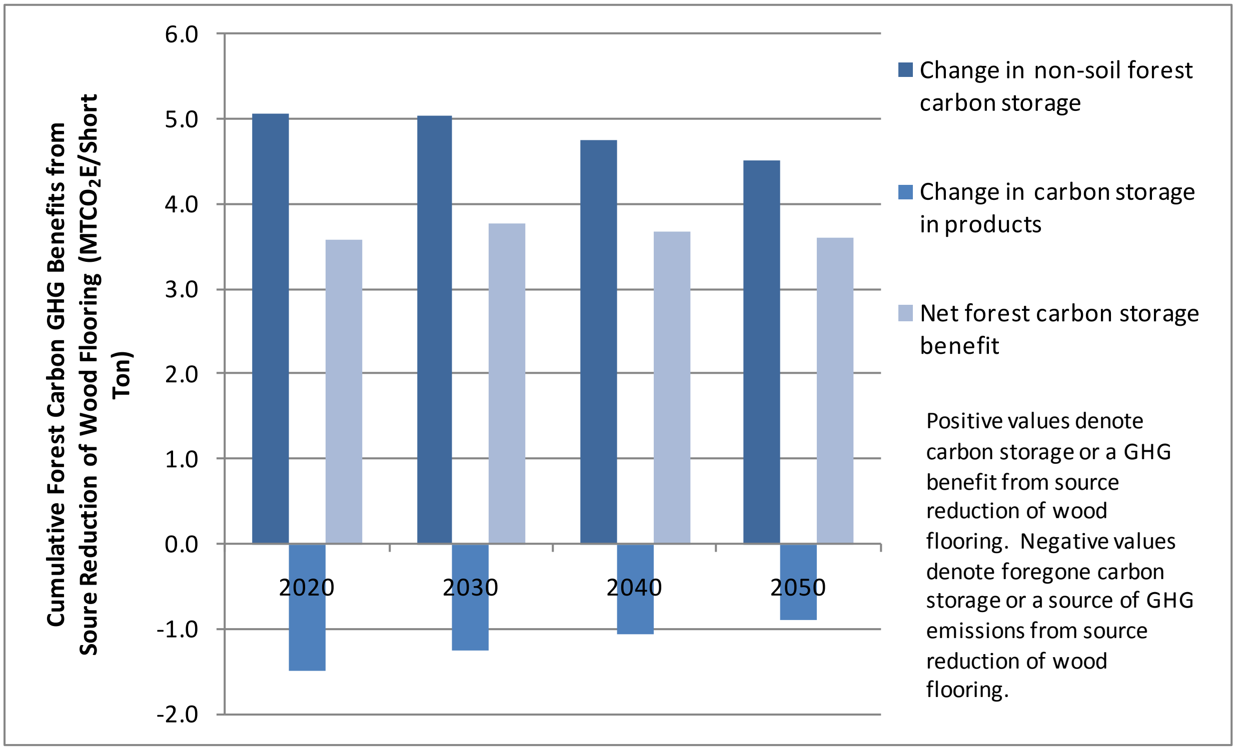


Exhibit 10: Forest Carbon Storage Calculations for Virgin Production of Wood Flooring

Material/Product	Forest Carbon Released	Carbon Released from Wood Products	Net Carbon Released
Wood Flooring	-4.84	1.18	-3.66

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.

The forest carbon storage estimate is subject to the same caveats and limitations discussed in the Forest Carbon Storage Section. Our results are also sensitive to the ratio of hardwood required to make flooring.

4.2 RECYCLING

Wood flooring that is in good condition at the end of a building's life can be recycled by using deconstruction or hand demolition to remove the flooring, followed by de-nailing, before reselling the wood for additional use (Falk & McKeever, 2004; Falk, 2002; Bergman, 2009). Larger wooden support timbers recovered from buildings prior to demolition can also be re-manufactured into wooden flooring. Although hand recovery of wood flooring is the most common procedure, heavy equipment such as power saws are increasingly being used to recover good-quality timbers and other materials during deconstruction (Bergman, 2009).

The USDA Forest Service has conducted primary data collection of recycled wood flooring and is in the process of compiling this data in a consistent LCI format. Since these data are not yet available, WARM does not include a recycling emission factor for wood flooring at this time.

4.3 COMPOSTING

Wood waste (including flooring) from C&D projects that has not been treated with chemical preservatives can be chipped or shredded for composting (FAL, 1998, pp. 3-7). While composting wood flooring is technically feasible, there is not much information available on composting wood products or the associated GHG emissions. As such, WARM does not consider GHG emissions or storage associated with composting wood flooring. However, this is a potential area for future research for EPA.

4.4 COMBUSTION

Flooring and other wood wastes form a part of "urban wood waste" that is recovered from demolition sites or at C&D material recovery facilities, sized using wood chippers, and used as boiler fuel or combusted for electricity generation in biomass-to-energy facilities or co-firing in coal power plants (FAL, 1998, pp. 3-7; Hahn, 2009). Combustion of wood emits biogenic carbon dioxide and nitrous oxide emissions. For more information on Combustion, please see the chapter on Combustion.

To model the combustion of wood flooring, EPA uses wood grinding fuel consumption data from Levis (2008, p. 231). FAL (1994) provides data on the GHG emissions from transporting wood flooring to a waste-to-energy facility and transporting the ash residue to landfill, assuming diesel fuel consumption. We assume the energy content of wood flooring is 9,000 BTU per pound, or 18 million BTU per short ton (Bergman and Bowe, 2008, Table 3, p. 454).

To calculate avoided utility emissions from energy recovery, EPA assumes that wood flooring is combusted in a biomass power plant to produce electricity, with a heat rate of 15,850 BTU per kWh electricity output (ORNL, 2006, Table 3.11). EPA assumes that the energy supplied by wood flooring combustion offsets the national average mix of fossil fuel power plants, since these plants are most likely to respond to marginal changes in electricity demand. Exhibit 11 summarizes the combustion emission factor for wood flooring.

Exhibit 11: Components of the Combustion Net Emission Factor for Wood Flooring ($MTCO_2E$/Short Ton)

Material	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Combustion	CO_2 from Combustion	N_2O from Combustion	Avoided Utility Emissions	Steel Recovery	Net Emissions (Post-Consumer)
Wood Flooring	–	0.05[a]	–	0.04	-0.84	–	-0.76

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
– = Zero emissions.
[a] Includes wood grinding, transportation to combustion facility, and transportation of ash to landfill.

In addition to biomass power plants, urban wood waste and wood flooring may also be used to fuel co-fired coal power plant facilities, or in utility boilers. EPA conducted research to investigate the share of urban wood waste sent for different energy recovery applications, but was unable to develop an estimate of the relative share of wood sent to each pathway. This is an area for further study that could help refine the avoided utility emissions calculated for the wood flooring combustion pathway.

4.4.1 Developing the Emission Factor for Combustion of Wood Flooring

Raw Material Acquisition and Manufacturing: Since WARM takes a materials-management perspective (i.e., starting at end-of-life disposal of a material), RMAM emissions are not included for this materials management pathway.

Transportation to Combustion: GHG emissions from transportation energy use were estimated to be 0.01 MTCE for one short ton of wood flooring (FAL, 1994).

CO_2 from Combustion and N_2O from Combustion: Combusting wood flooring results in emissions of nitrous oxide (N_2O) and those emissions are included in WARM's GHG emission factors for wood flooring.

Avoided Utility Emissions: Most waste-to-energy (WTE) plants in the United States produce electricity. Only a few cogenerate electricity and steam. In this analysis, EPA assumed that the energy recovered with MSW combustion would be in the form of electricity, and thus estimated the avoided electric utility CO_2 emissions associated with combustion of waste in a WTE plant (Exhibit 12).

Exhibit 12: Utility GHG Emissions Offset from Combustion of Wood Flooring

(a) Material/Product	(b) Energy Content (Million Btu per Short Ton)	(c) Combustion System Efficiency (%)	(d) Emission Factor for Utility-Generated Electricity ($MTCO_2E$/ Million Btu of Electricity Delivered)	(e) Avoided Utility GHG per Short Ton Combusted ($MTCO_2E$/Short Ton) (e = b × c × d)
Wood Flooring	18.0	21.5%	0.22	0.84

Steel Recovery: There are no steel recovery emissions associated with wood flooring because it does not contain steel.

While N_2O and transportation emissions for wood flooring are positive emission factors, a greater amount of utility emissions are avoided, so the net GHG emissions for combustion are negative for wood flooring.

4.5 LANDFILLING

Landfill emissions in WARM include landfill methane and carbon dioxide from transportation and landfill equipment. WARM also accounts for landfill carbon storage, and avoided utility emissions from landfill gas-to-energy recovery. Wood flooring is an biodegradable material that results in some landfill methane emissions and carbon sequestration. Because C&D landfills generally do not have flaring systems, most of that methane is released to the atmosphere (Barlaz, 2009). In addition to these emissions, we assume the standard WARM landfilling emissions related to transportation and equipment use (EPA, 2006, p. 93). Staley and Barlaz (2009) provide data on the moisture content, carbon storage factor, and methane yield of wood flooring. Due to lack of information about the decay conditions in C&D landfills, the landfilling emission factor assumes that the same conditions prevail as at municipal solid waste landfills, except that no collection of methane occurs. The methane and transportation emissions outweigh the carbon sequestration benefits, resulting in net emissions from the landfill, as illustrated in Exhibit 12. For more information on Landfilling, please see the chapter on Landfilling.

Exhibit 13: Landfilling Emission Factor for Wood Flooring ($MTCO_2E$/Short Ton)

Material	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Landfill	Landfill CH_4	Avoided CO_2 Emissions from Energy Recovery	Landfill Carbon Storage	Net Emissions (Post-Consumer)
Wood Flooring	–	0.04	–	–	–	0.04

— = Zero emissions.

5. LIMITATIONS

Composting is not included as a material management pathway due to a lack of information on the GHG implications of composting wood products. The composting factor in WARM, described in the Composting chapter, assumes a generic compost mix, rather than looking at materials in isolation. It is not currently known what effect adding large amounts of wood would have at a composting site, whether the GHG emissions or sequestration would be altered, or whether the carbon-nitrogen ratio would be affected. As a result, EPA has not estimated emission factors for composting. However, EPA is planning to conduct further research into this area that could enable better assessments of composting emission factors for wood products.

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